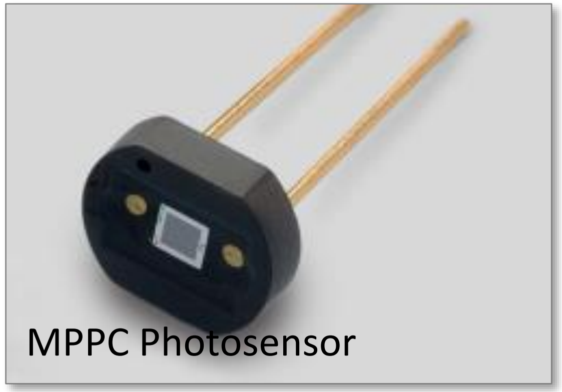
VIDARR

Jon Coleman, on behalf of the project

University of Liverpool · Science & Technology Facilities Council · The Royal Society · Innovate UK Technology Strategy Board · National Nuclear Laboratory · JCS

In the beginning: The ND280 ECal

- Electromagnetic Calorimeter consists of:
  - Active scintillator bars read out with WLS + MPPCs
  - Sandwiched with lead sheets
  - Magnetic field using UA1 Magnet Yoke
  - Major Liverpool involvement in design and construction
  - Survived the 2011 Earthquake



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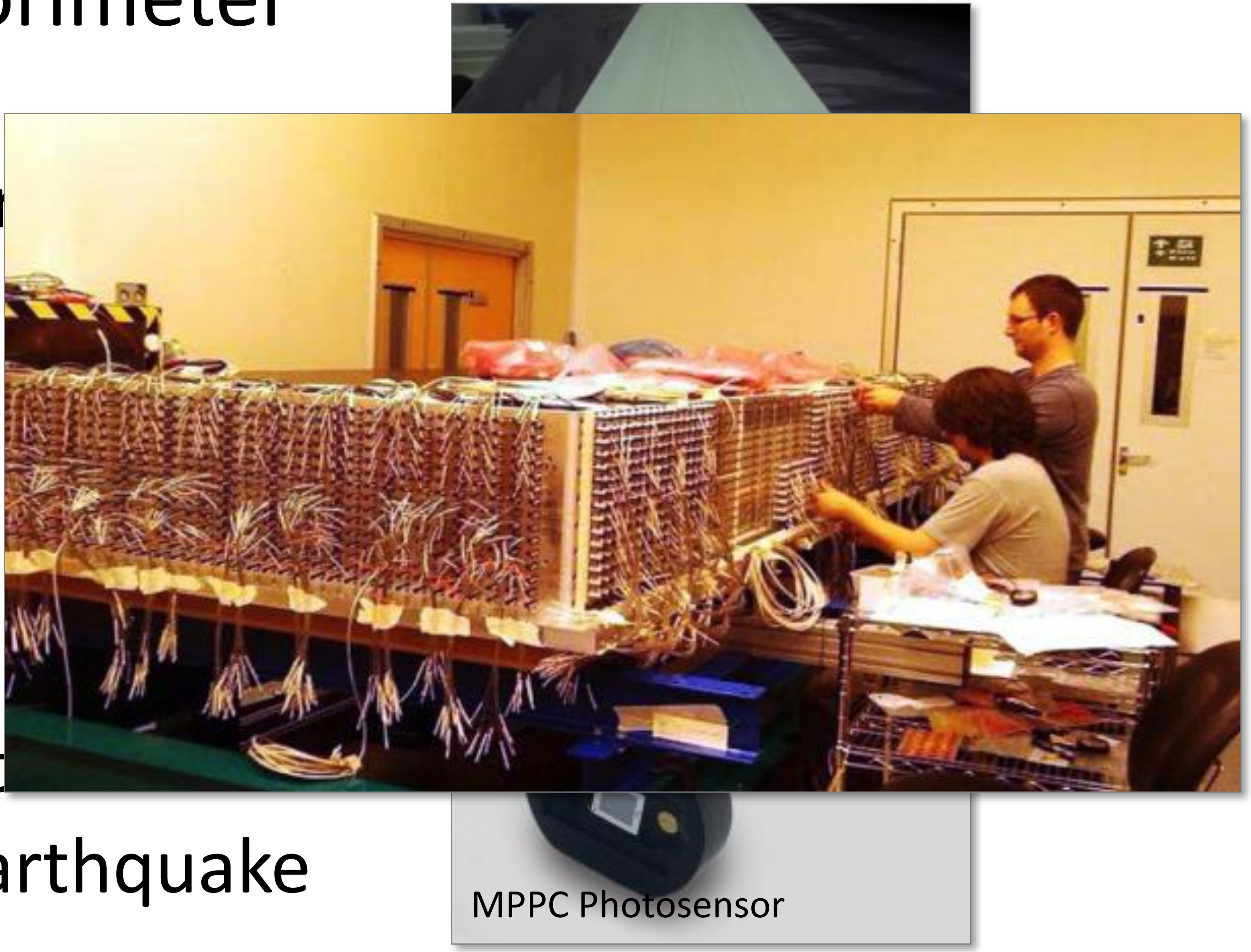


MPPC Photosensor

Detecting inverse β-decays

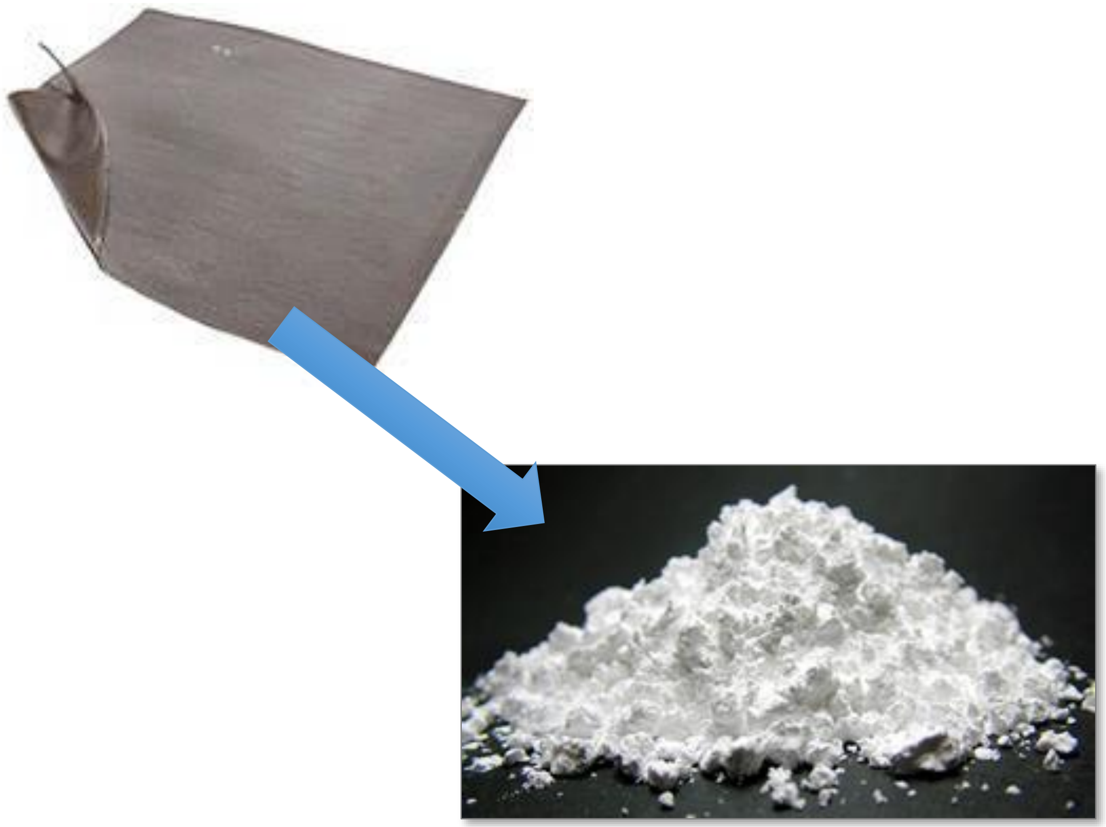
- Needed to modify the ECal
- Different signatures and environment than T2K
- Three main challenges:
  - Neutron detection
  - Trigger & DAQ
  - Aboveground operation

Neutron Detection

- Replacing lead with Gadolinium

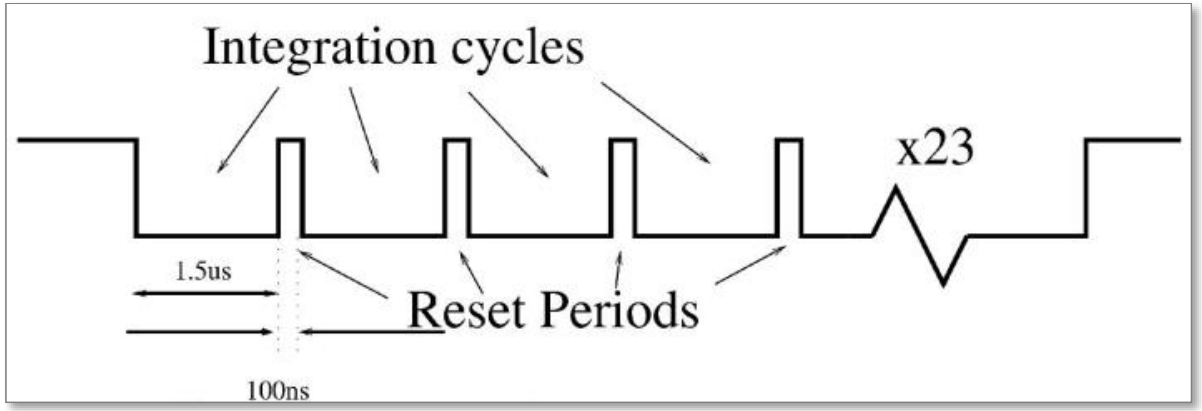
- Provides ability to capture neutrons
    - Gd has second highest capture cross-section

- Produces characteristic 8 MeV γ-ray cascade
    - Compton scattering in detector



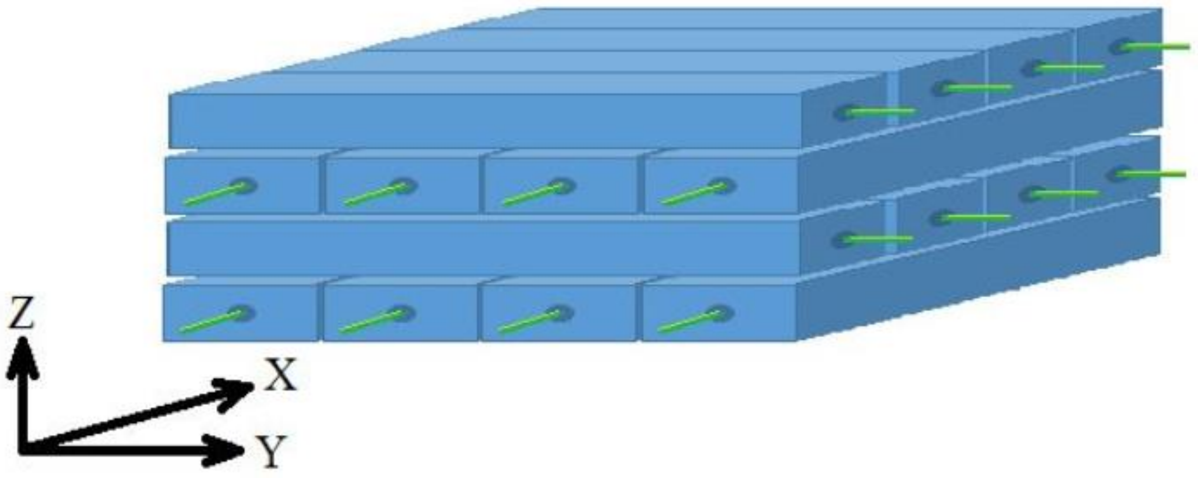
Trigger & DAQ

- Based on Trip-T chips (DØ and T2K)
- Front- and backend readout uses T2K hardware with modified firmware
- Changing from beam trigger to neutron trigger
  - Uses number of bars above threshold and total energy
- FIFO buffer of integration cycles stores data pre-trigger
  - Read-out upon trigger



Aboveground Operation

- Muon veto:
  - Implemented on trigger level
  - Reduces data rate and avoids deadtime



- Muon tracking:
  - Analysis level
  - Uses detector layout to identify tracks

Mobile Container Lab

- Full-scale prototype:
  - 1.7m x 1.7m x 0.8m
  - c. 1 ton active mass
  - c. 2000 channels
- Housed in climate controlled 20 ft. ISO shipping container
- Transport using standard HIAB truck

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Liverpool Prototype Detector

Requirement	Solution	
Inert construction	Plastic scintillator	✔
Non-liquid	Plastic scintillator	✔
Easy operation	Low voltage SiPMs (< 120 V)	✔
Cheap	Extruded plastic	✔
Portable	Detector & services in ISO container	✔
Robust	Proven T2K ECal design	✔
Aboveground operation	Integrated cosmic ray veto	✔
Easy deployment	ISO container only requires 3-phase power plug	✔

c.f.: “Final Report: Focused Workshop on Antineutrino Detection for Safeguards Applications”, IAEA (2008)

The Wylfa Magnox Power Plant

- Detector deployed 2014-2015

- Was last operating Magnox reactor in UK
  - Magnox design has been exported
  - Originally, two cores, one active during deployment
  - Final shutdown end of 2015

- Detector deployed c. 60m from reactor
  - Position outside inner security barrier (ISB)
  - Close to 3-phase power outlet

The Wylfa Magnox Power Plant

Challenges of Power Plants

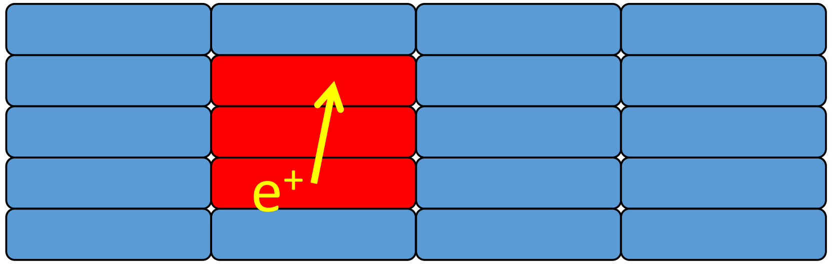
- **Not a research reactor**

- Due to safety and security protocols:
  - Limited access
  - No standard connection to detector (dial-up modem!)
  - Need to write safety case
  - ‘dirty’ power

Resolvable Problems

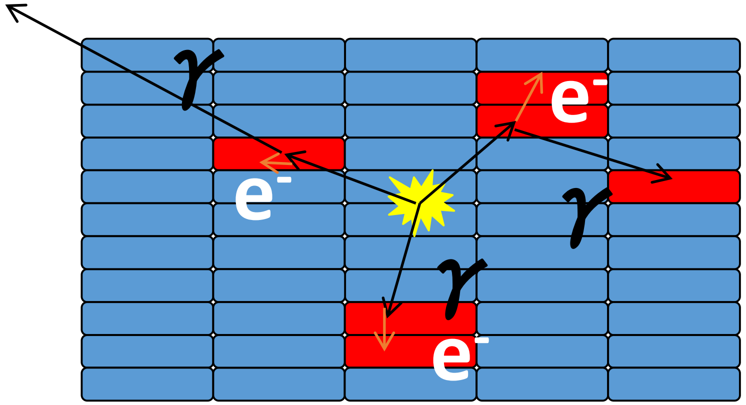
Event Signatures

Positron



- Contained track
- Concurrent in time
- $E_{max} \approx 8$ MeV
- Immediately after inverse β-decay

Neutron



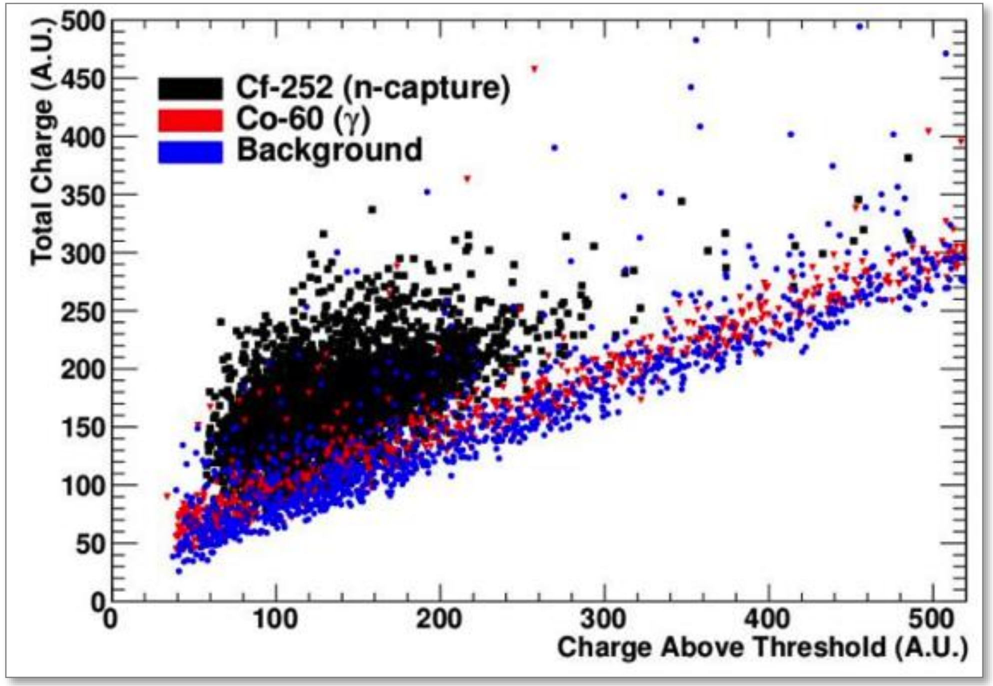
- 8 MeV γ cascade upon capture
- Multiple Compton scatters (many small hits)
- Spatially diffuse hits coincident in time
- Ca. 10 μs after positron

Event Selection

- Positron:
  - Continuous track/cluster
  - Short length
  - Only single positron in event

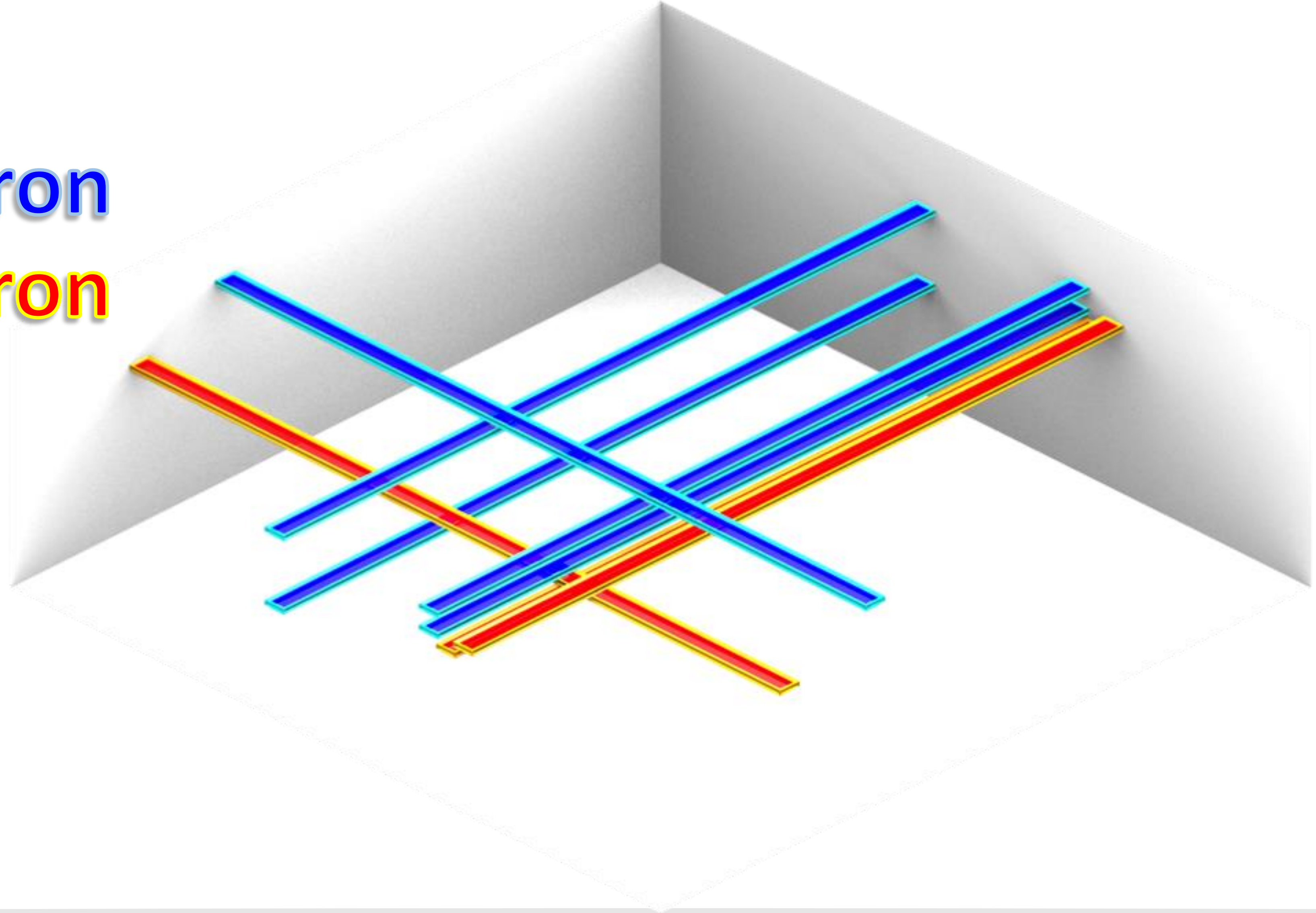
- Neutron:
  - Ratio of bars and total energy
  - Cluster size
  - Based on source measurements

Example neutron source data for particle ID

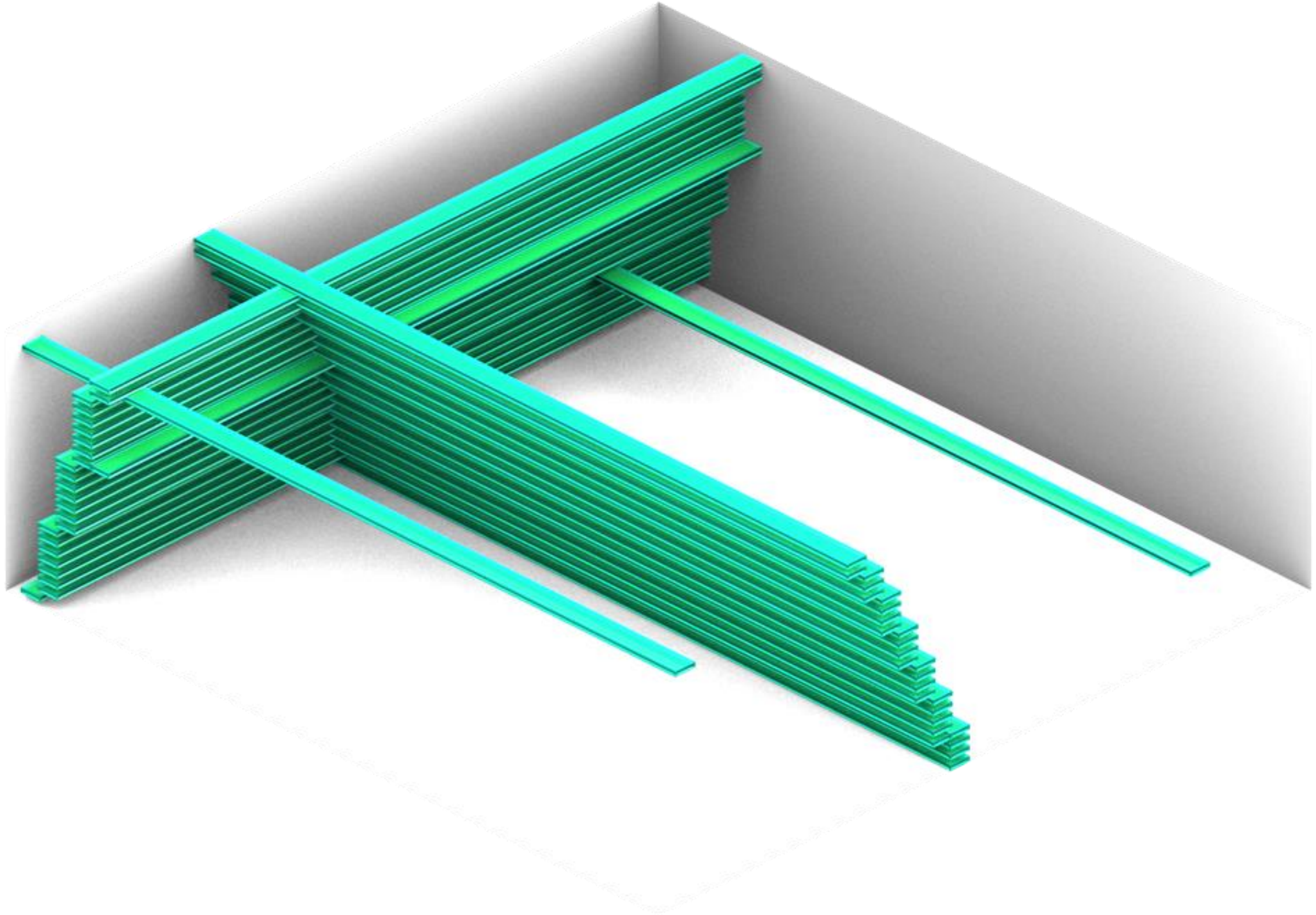


Event Display

Neutron
Positron

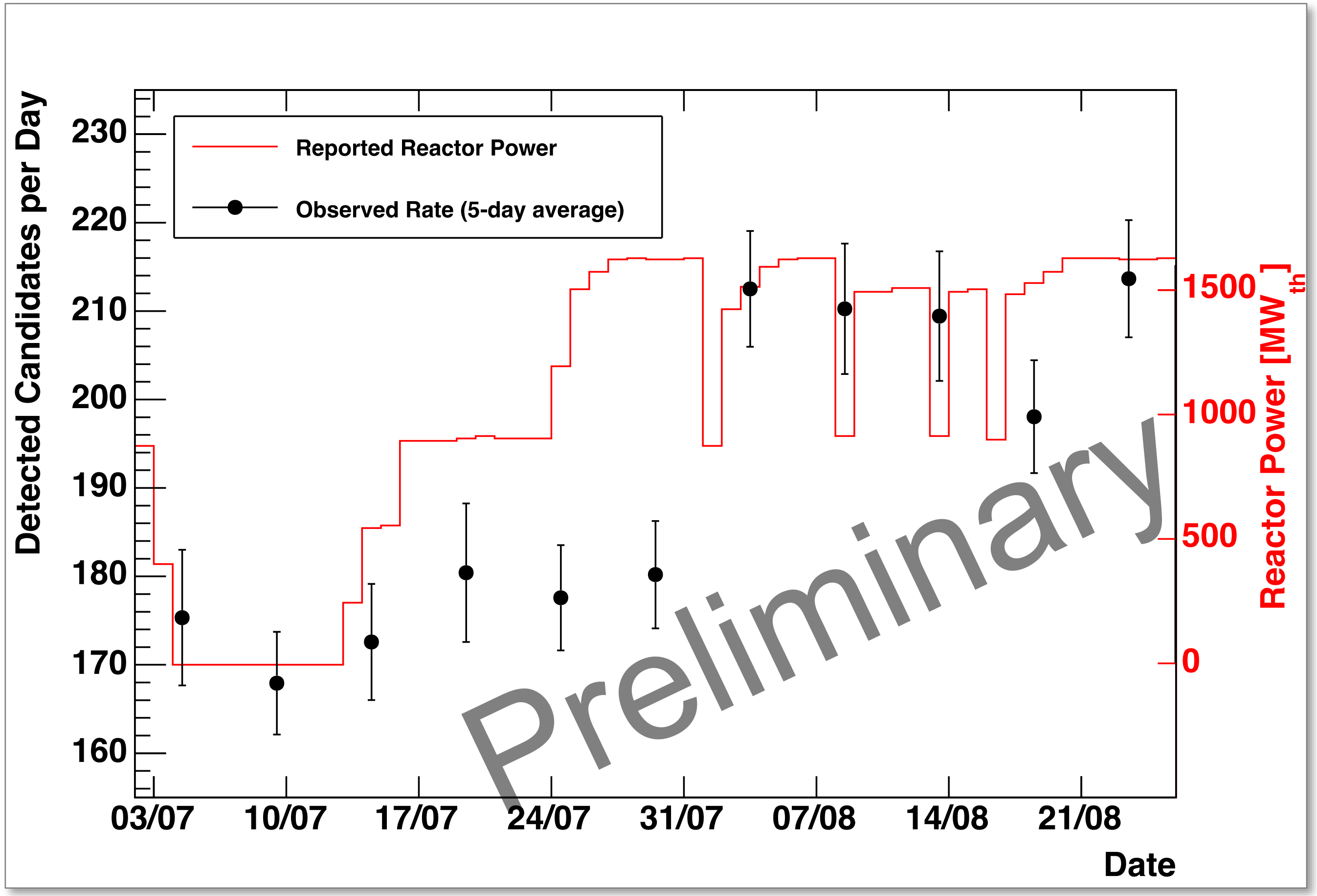


Event Display



Result: Preliminary Observation

- Reactor turn-on after refuelling
- 1.6 GWth power
- At 60m distance
- Using self-contained mobile laboratory (20 ft. ISO container)



Return to Liverpool

- After Wylfa shutdown:
  - Detector returned to Liverpool early 2016
  - Background studies started
- Upgrade programme under Innovate-UK grant with JCS Nuclear Solutions
- Collaboration with National Nuclear Laboratory

JCS Nuclear Solutions

Innovate UK Technology Strategy Board

NATIONAL NUCLEAR LABORATORY

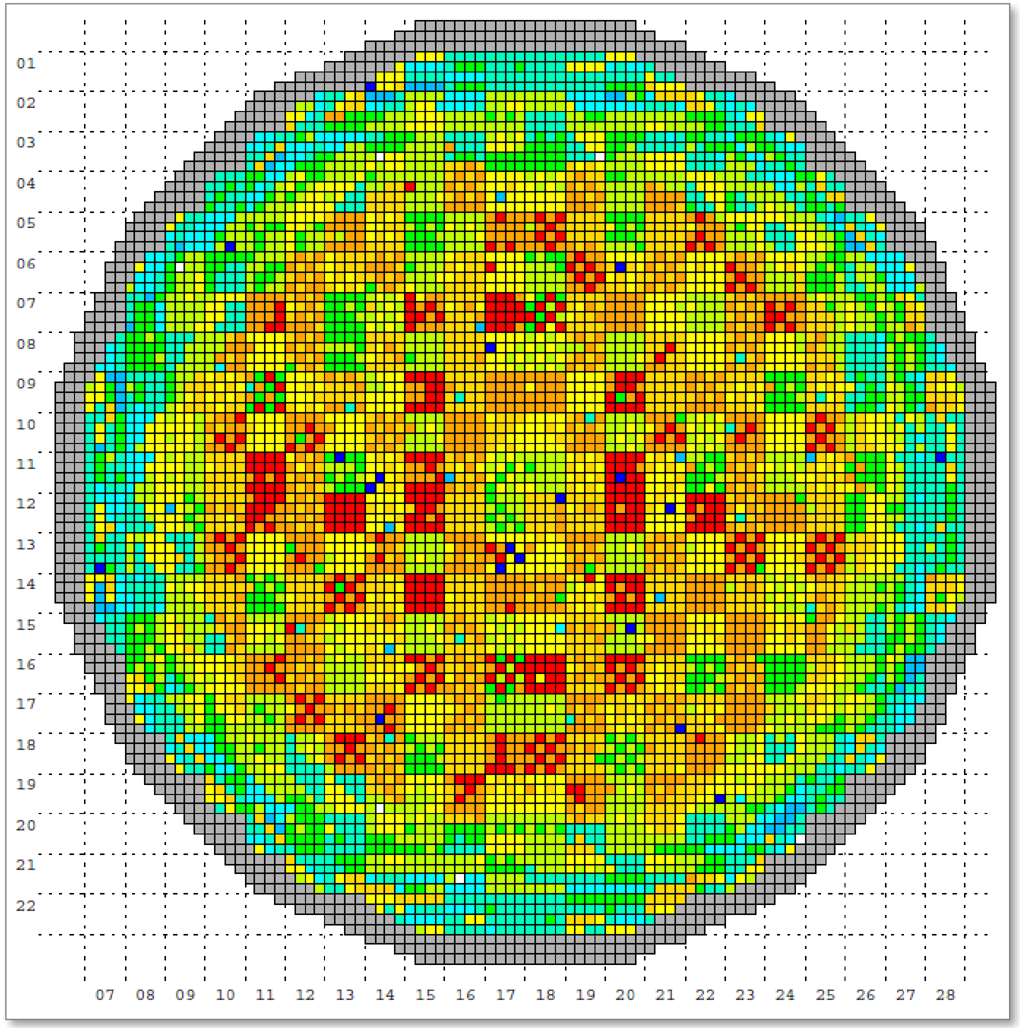
Reactor Simulation

NATIONAL NUCLEAR LABORATORY

- Collaboration with NNL:
    - Access to core data (usually not accessible)
    - Highly experienced with core modelling
    - Strongly involved in nuclear data bases used for understanding β-decay chains

- Can produce anti-neutrino flux predictions at detectors
    - On full pin-by-pin level

from Robert Mills



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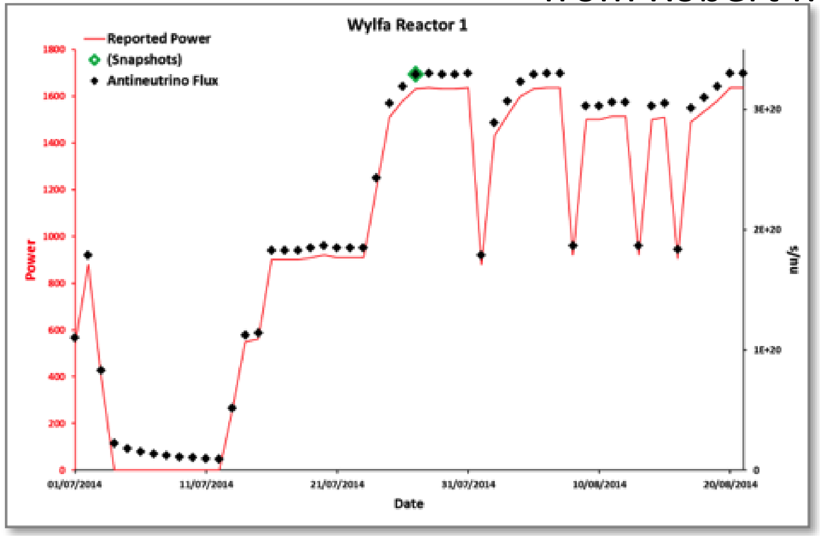
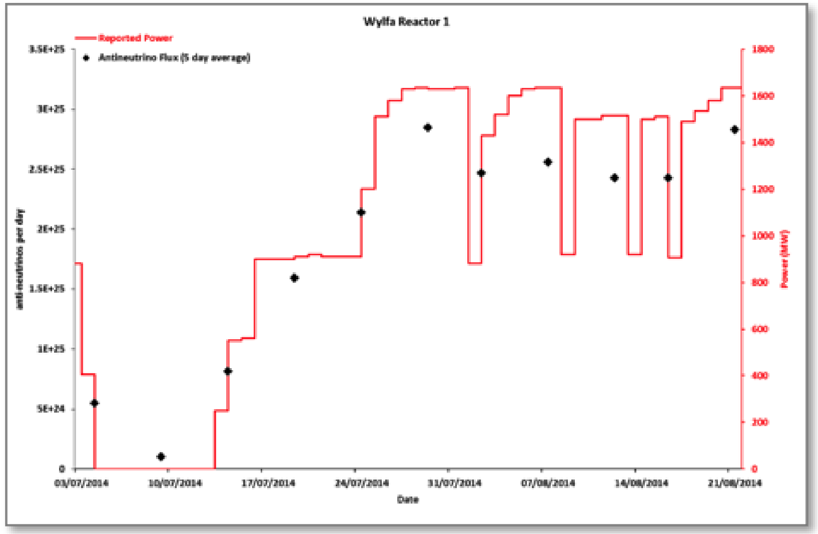
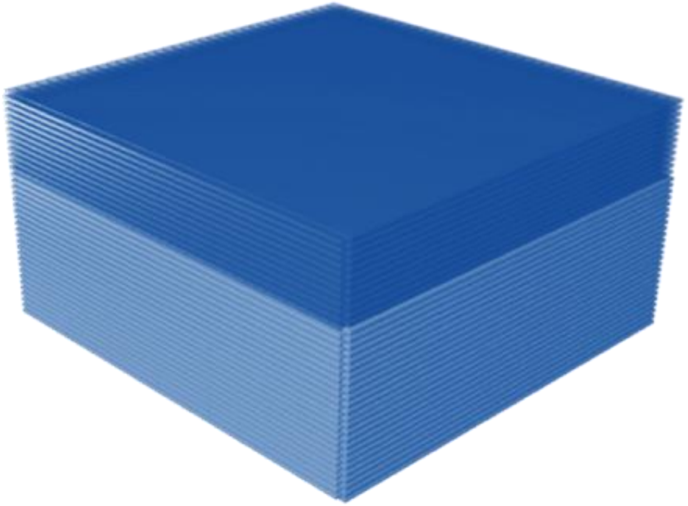




Improving performance and future outlook

Mass Upgrade

- First generation system has space mass upgrade (allows re-use of frame)
- Additional c. 50% active mass
- Increasing layer count from 49 to 70
- Scintillator arrived end of 2017



Upgraded MPPCs

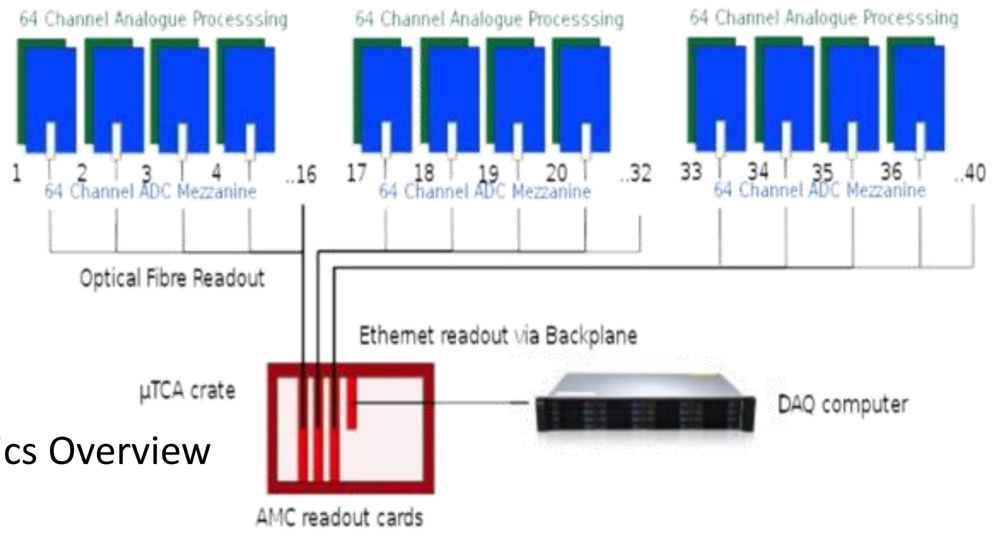
- First generation used T2K-type MPPCs
- Upgrade to newest MPPCs
- New MPPCs characterised

Sensor	Quantum Efficiency [%]	Gain	Dark Noise	Crosstalk	Dynamic Range
PMT	30-40	$O(10^6)$	kHz - Hz		Large
T2K MPPCs	20-30	$3x10^5$	$O(10^6)$	10%	100s photons
Latest MPPCs	40-60	$3x10^6$	$O(10^4)$	2%	100s photons

New Electronics

- 64-channel analogue board
- 64-channel Fast ADC mezzanine board

- Optical fibre link to µTCA backend board (AMC)
- 3 AMC boards connected to DAQ computer via ethernet

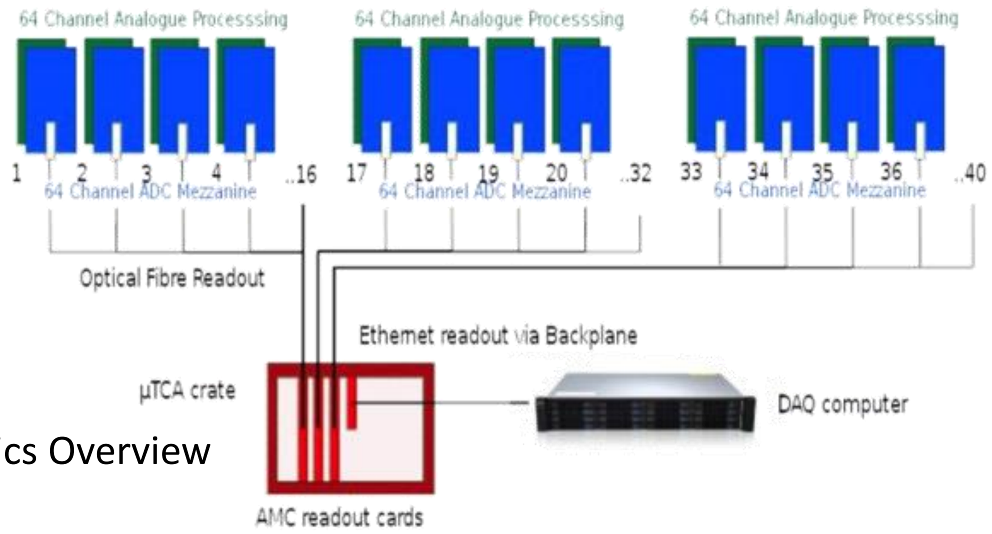


Electronics Overview

Prototype Analogue Board

New Electronics

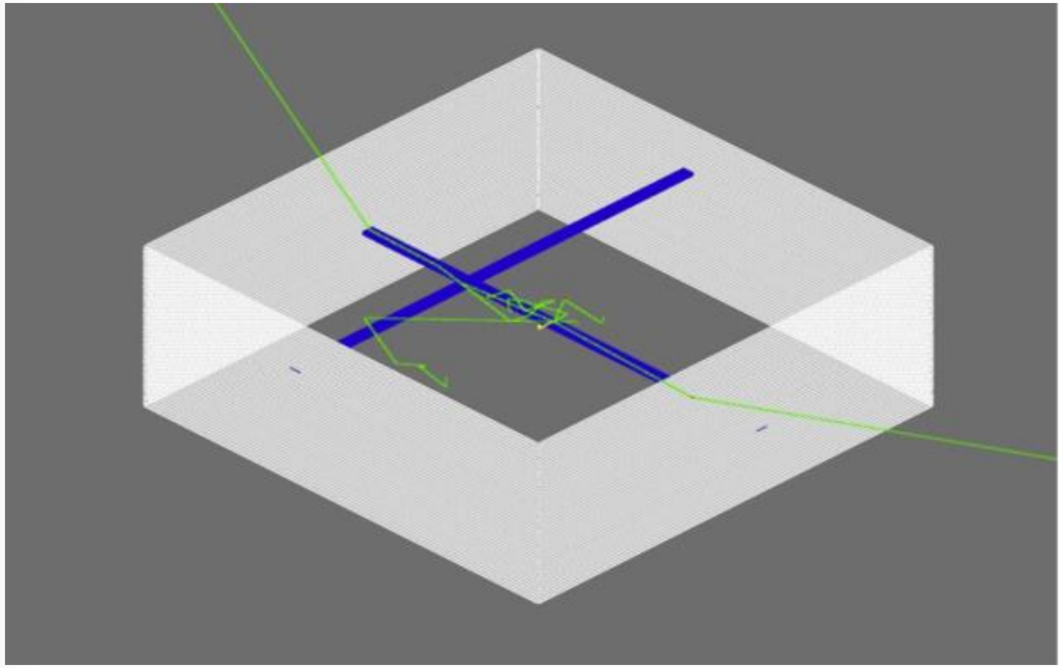
- Made for new MPPCs
- 'deadtime-less'
- lower data taking threshold (1-2 PE)
- higher time resolution (10s of ns)
- longer coincidence buffer (up to 100 μs)
- Boards in production

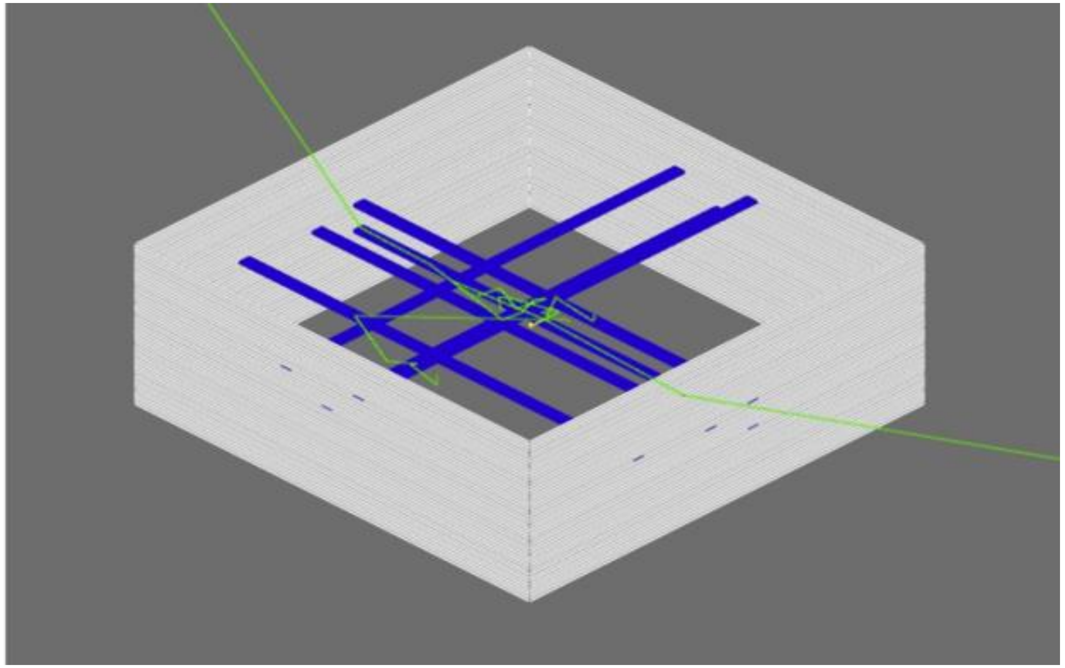


Electronics Overview

Prototype Analogue Board

Simulated Neutron Event





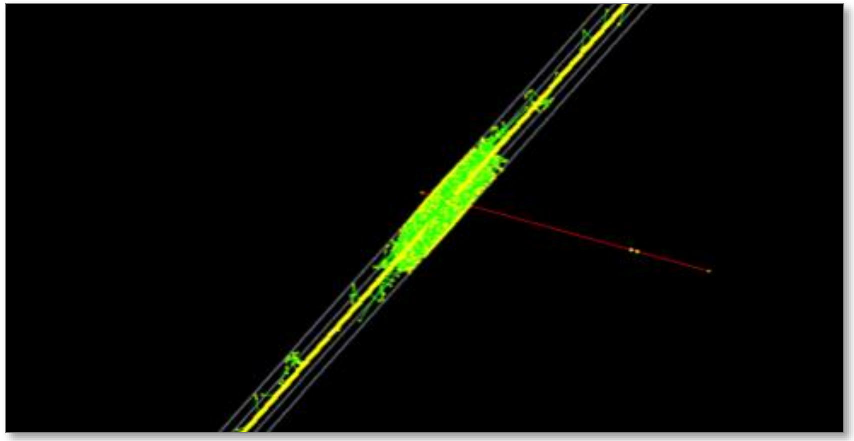
- High threshold: 700 keV
- Number of channels: Low

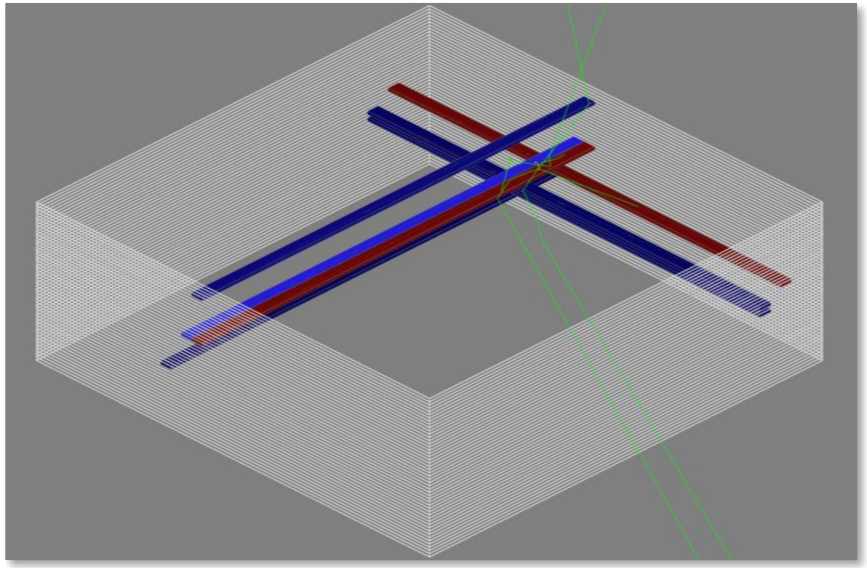
- Reduced threshold: 100 keV
- Number of channels: High
- Spatially separated hits

Detector Simulation

- Implemented full GEANT4 simulation of detector
  - Optical model of bar + MPPCs
  - Full detector model

- Used to model detector upgrade:
  - Studying performance of new MPPCs
  - Simulation of new electronics
  - Modelling of new triggers





Up[graded Detector

Based on operational experience & technology advances

- Additional mass and channels
- Improved MPPCs & new readout system
  - Leads to lower thresholds
- Full Detector and Reactor Simulations
- Improved Trigger

Acknowledgements

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  - **NNL staff are** funded by a multi-year strategic internal research and development project

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  Magnox Ltd at Wylfa Power Station: G Davies, A Roberts, A Tobias

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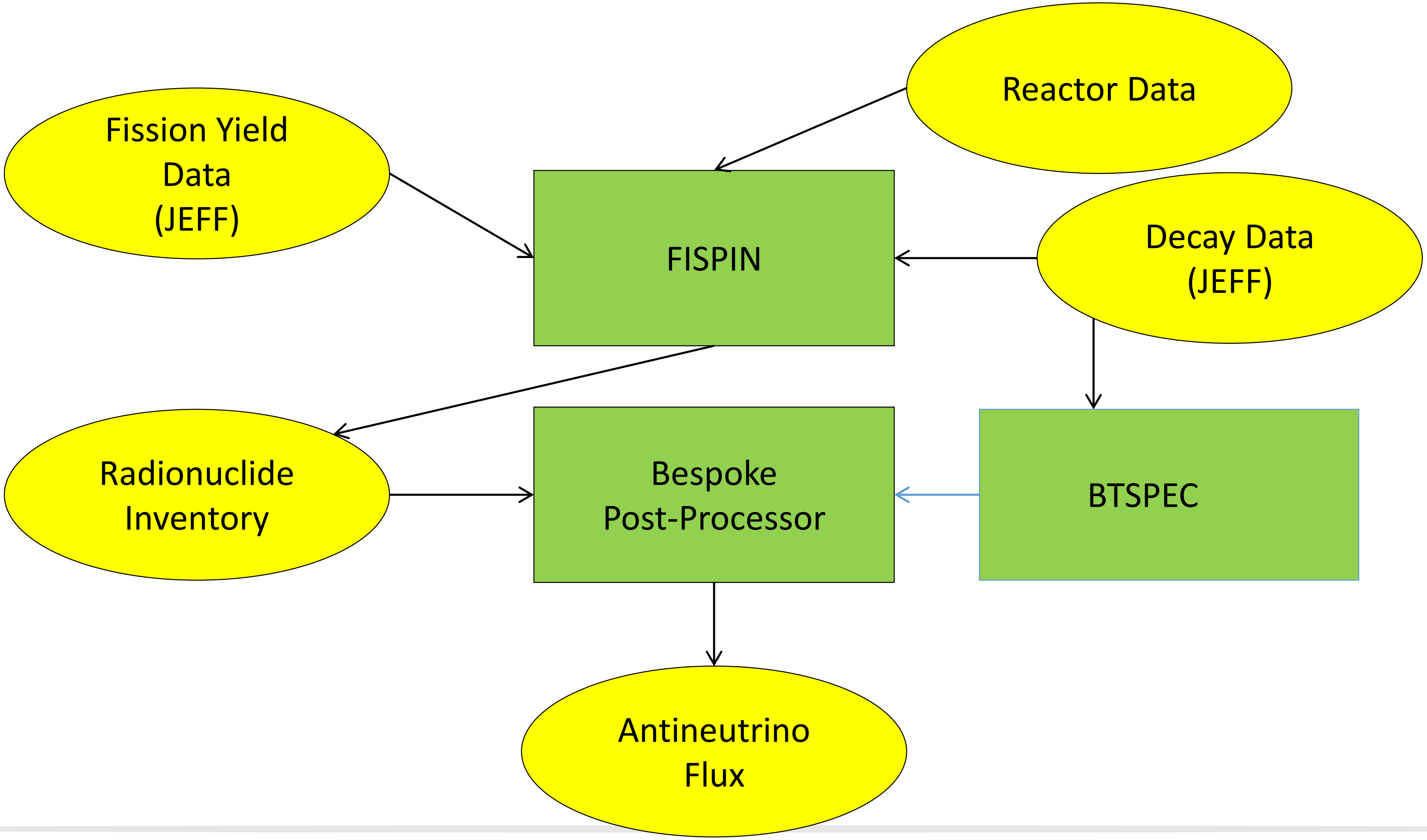
Backup

Flux Calculation



Known issues with anti-neutrino calculation

- BTSPEC code is 35 years old; physics from the 1970's and 1980's.
- JEFF-3.1.1 radioactive decay data only has beta spectra information for 670 nuclides of > 1000 needed (~90% of beta decays, but majority of anti-neutrinos >1.8 MeV from the 670).
- Uncertain if spectral data is experimental or theoretical approximation, no estimate of accuracy.
- In current work BTSPEC is used to generate 1500 bins of 10 keV width (i.e. maximum of 15 MeV) for all 670 nuclides.

- Work done so far used FISPIN to generate inventories for all 49248 rods in core during each day of irradiation with irradiation/cooling history.